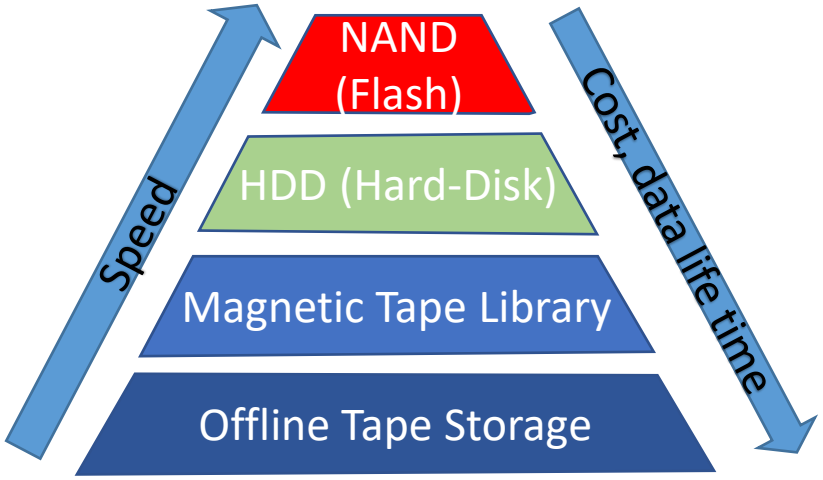
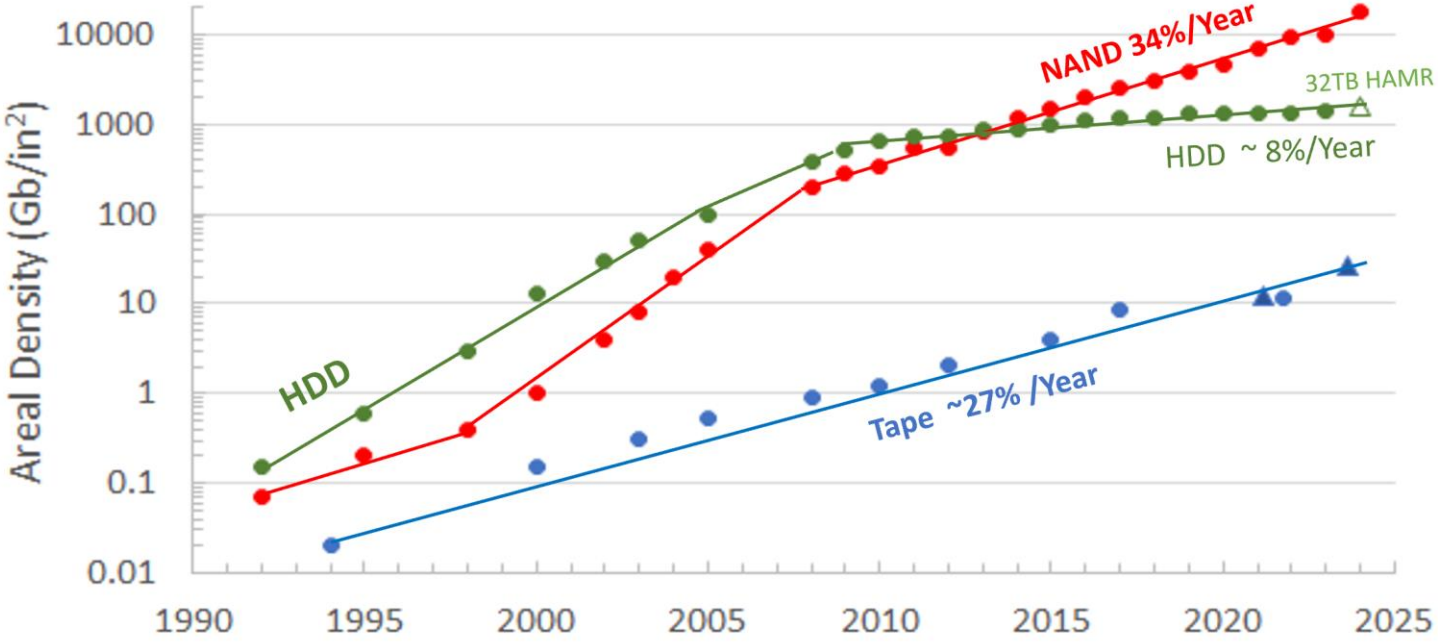
Data Storage Trends: NAND, HDD and Tape Storage

Georg Lauhoff, Sassan Shahidi
IBM Tape Storage, IBM Almaden, San Jose





This talk builds on studies by
G. Lauhoff et al, "Storage Infrastructure in the AI Era," IEEE Trans Mag 61, 4 (2025)
R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018).

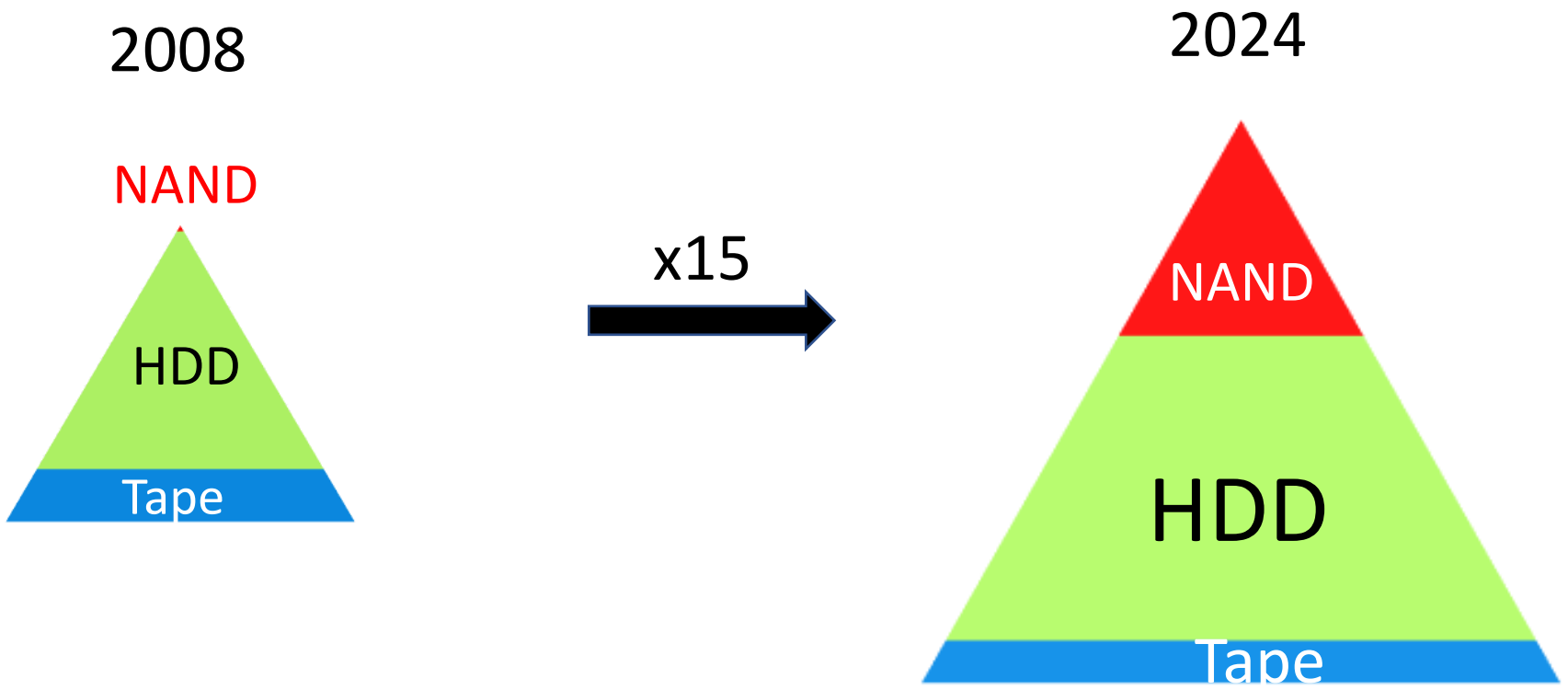
Library of Congress, Washington DC
Designing Storage Architecture for Digital Collections, March 24, 2025

Introduction/Summary

- **Archival Storage**: Tape data storage is reliable and cost-effective and energy conserving with no viable alternatives available.
- **Trends in Tiered Data Storage**: NAND and Tape improve @ historical rates in cost and storage densities while HDD progress slowed down
- **Challenges of Alternative Archival Technologies**: Despite the promise of alternative archive storage technologies, challenges persist. Enduring relevance of tape storage, which itself is rapidly evolving.

A Changing Data Storage Landscape

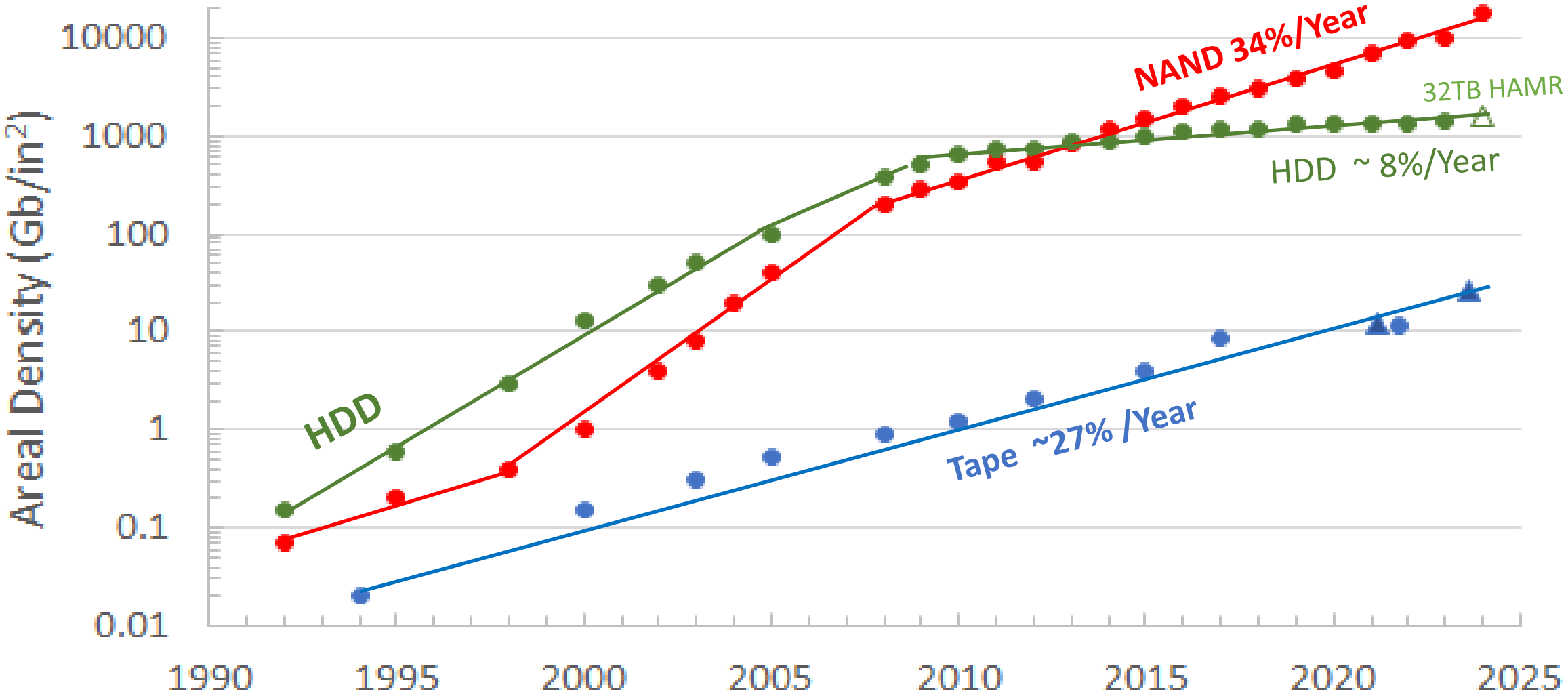
Annual capacity Shipments (Bits)



Data Storage trends for NAND (Flash), HDD and Tape Storage reviewed in this talk

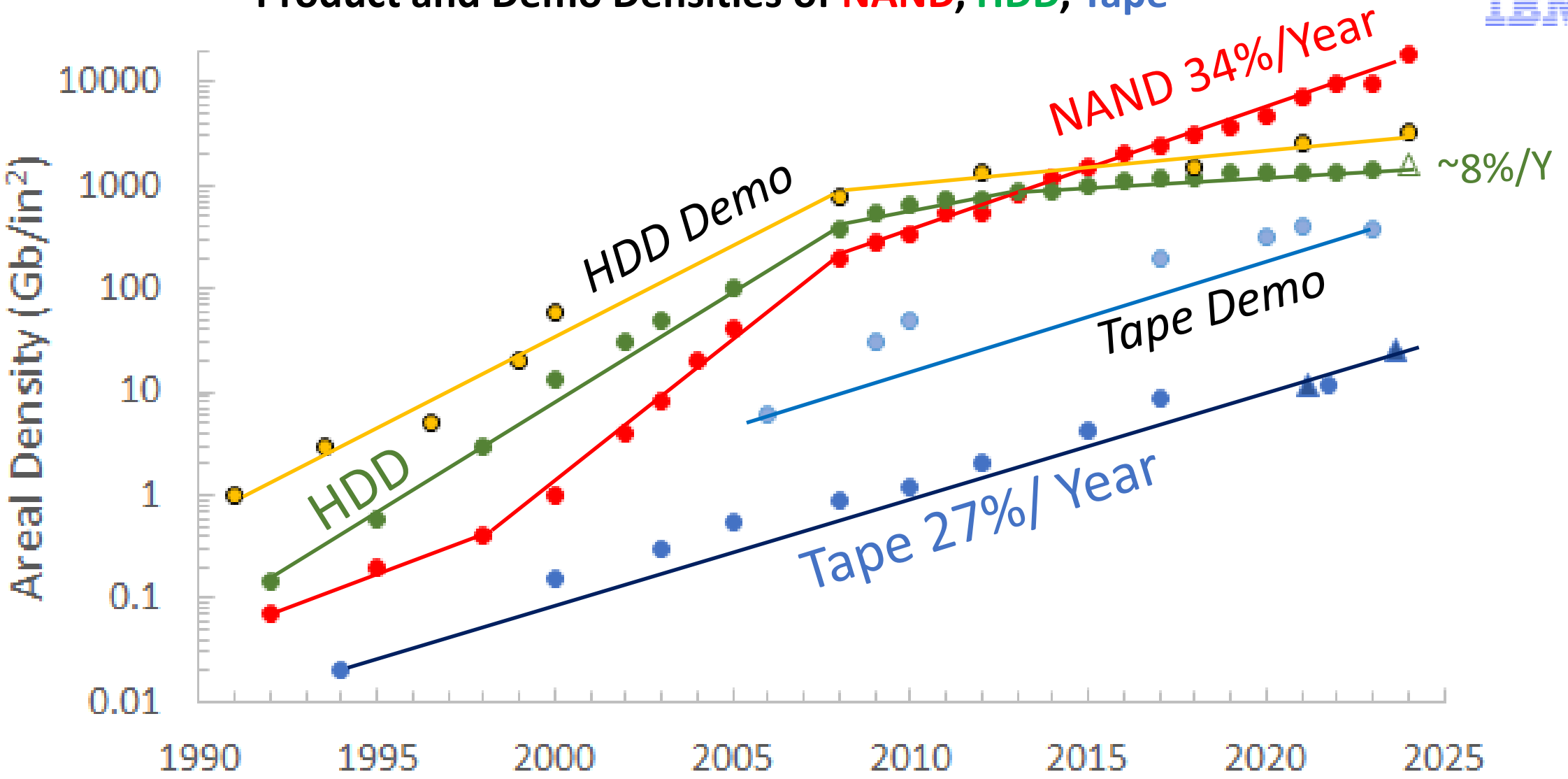
Data obtained from publicly available sources

Products **Areal Densities of NAND, HDD, Tape**



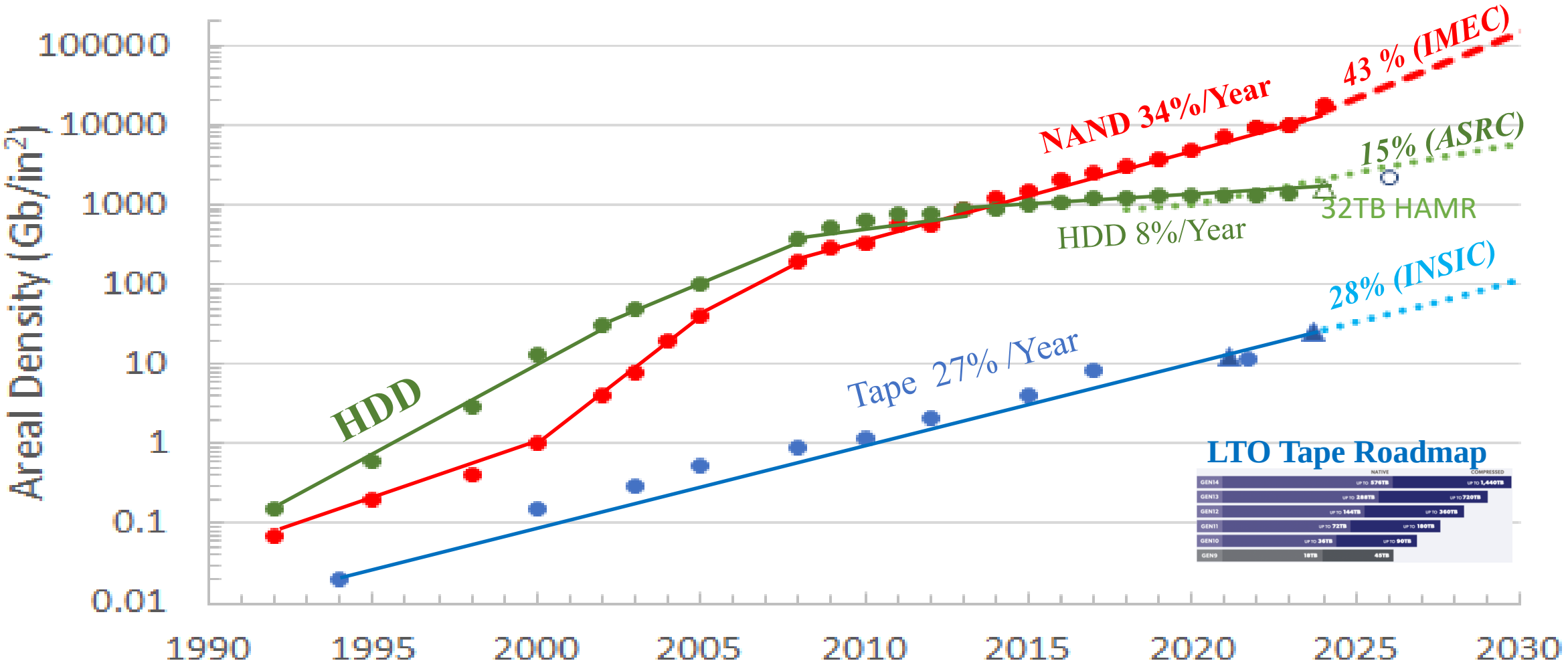
Tape and NAND improves more than HDD in areal densities

Product and Demo Densities of NAND, HDD, Tape



Tape has clear path to higher densities as demonstrated by demos;
With more investments more can be achieved in even shorter time

Product Areal Densities and Forecast



***NAND** and **HDD** forecast more optimistic compared to recent trend*

Forecast and product improvements similar for Tape

Recent Products and Forecasts

NAND (by IMEC)

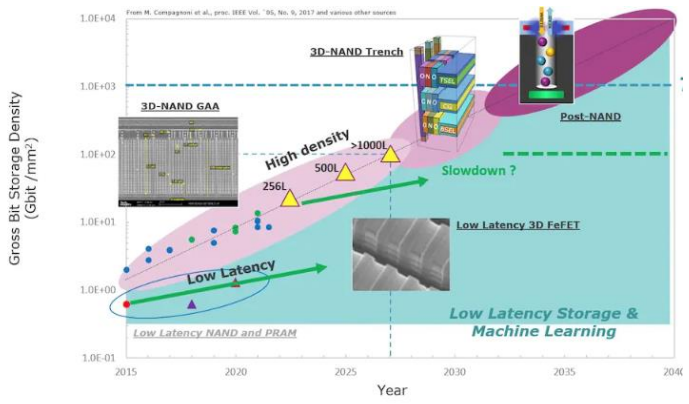
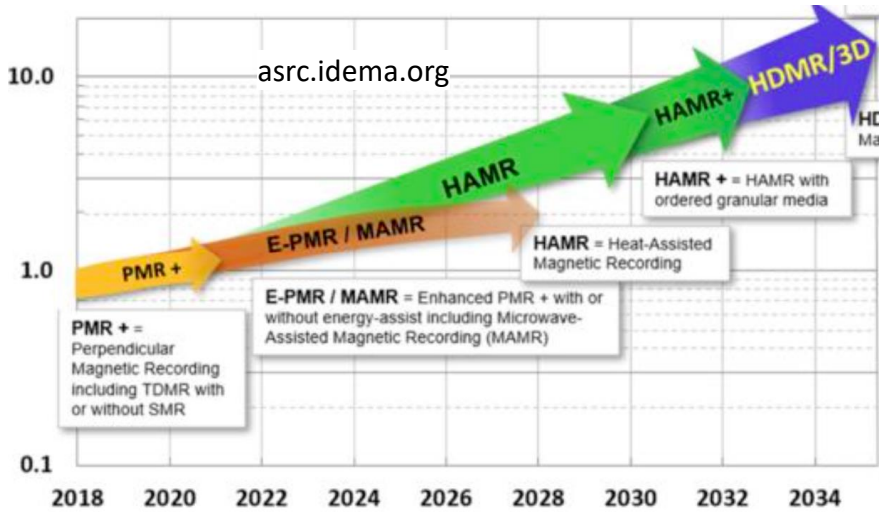
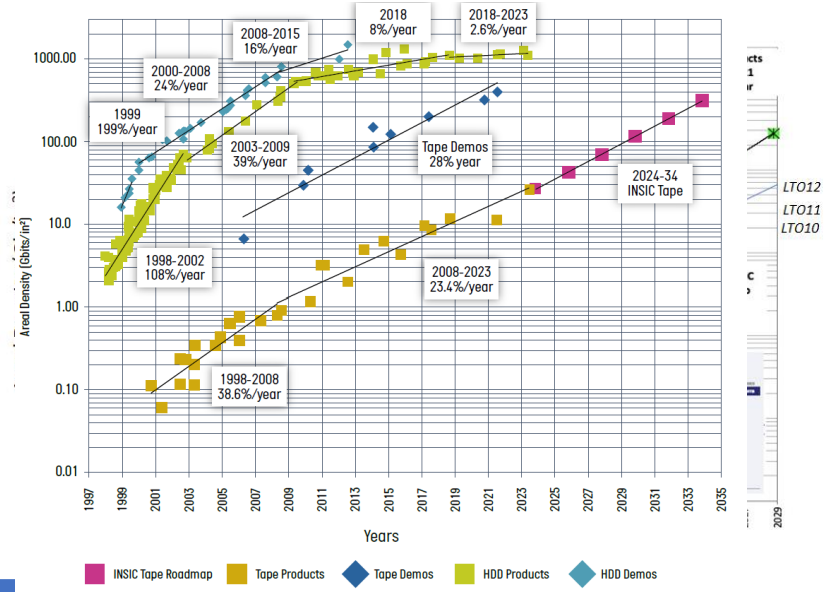


Figure 6: An imec view on the data storage roadmap.

HDD (by IDEMA 2022)



Tape (by INSIC 2024)

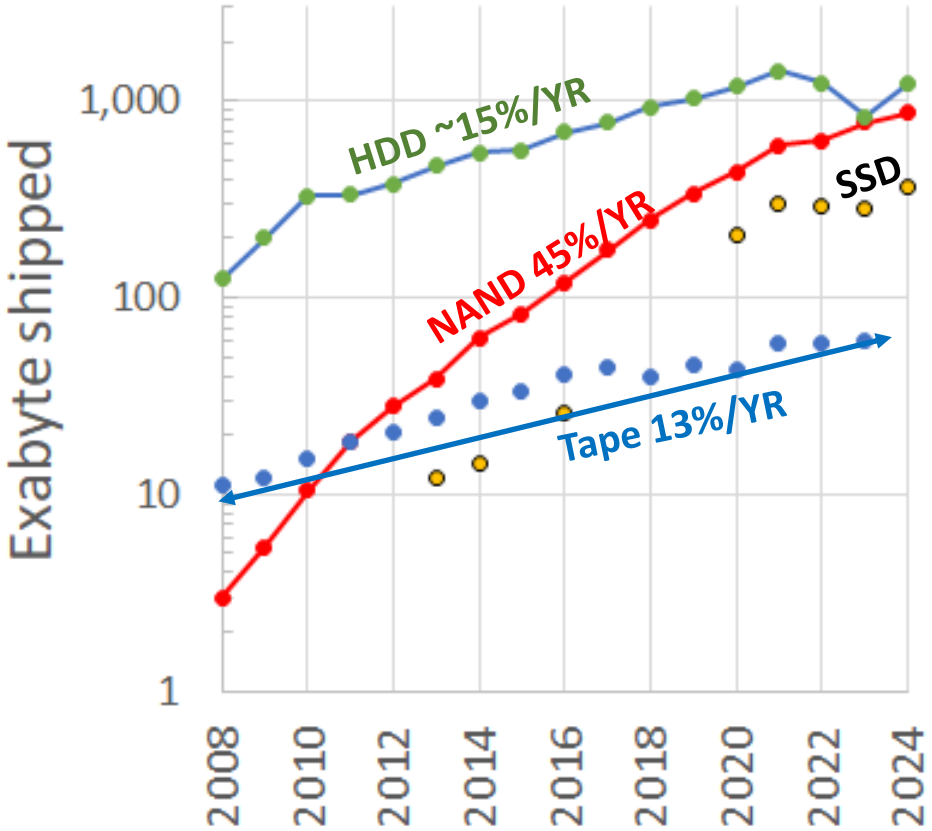


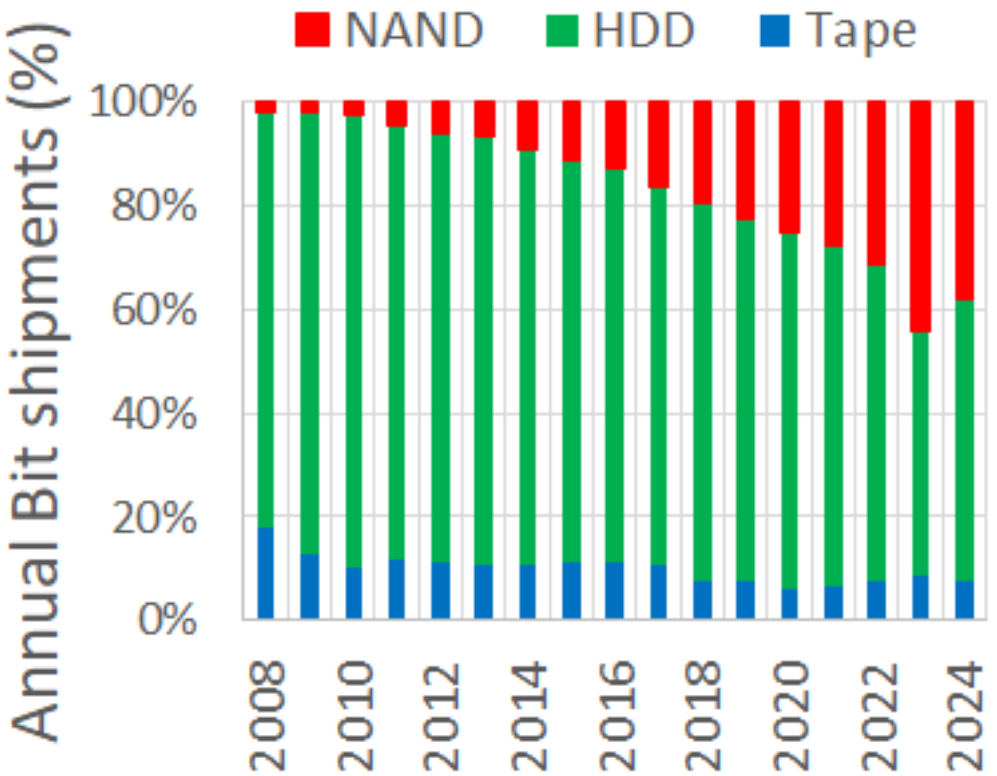
Areal Density Yearly Change			
	NAND	HDD	LTO TAPE
Products since 2012	33%	8%	27%
Roadmaps shown above	43%	15%	28%

Future Roadmaps predict stronger growth compared to recent product improvements!

NAND Projection from : https://www.imec-int.com/en/articles/role-3d-nand-flash-and-fefet-data-storage-roadmap
HDD Projection from : https://www.asrc.idema.org
Tape Projections adapted from INSIC

Annual Bit Shipments





2024	EB	%
NAND	867	39%
SSD	369	16%
other	498	22%
HDD	1,227	55%
LTO Tape	153	7%

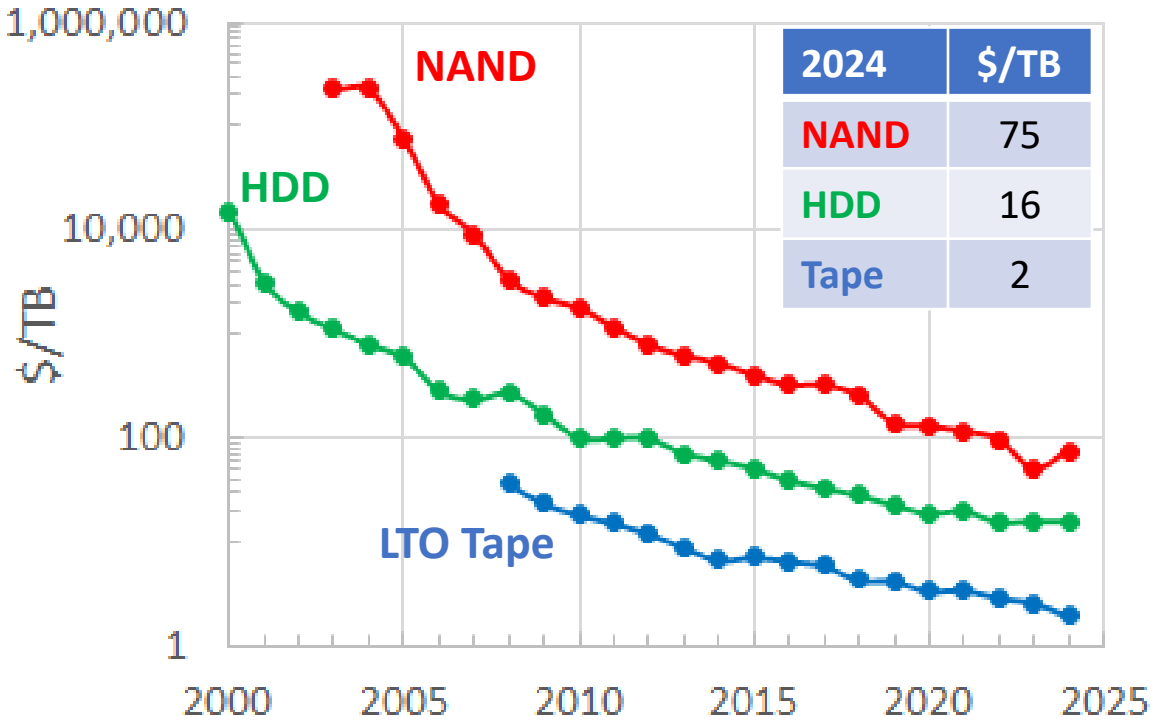
NAND and HDD bit shipments approaching each other.

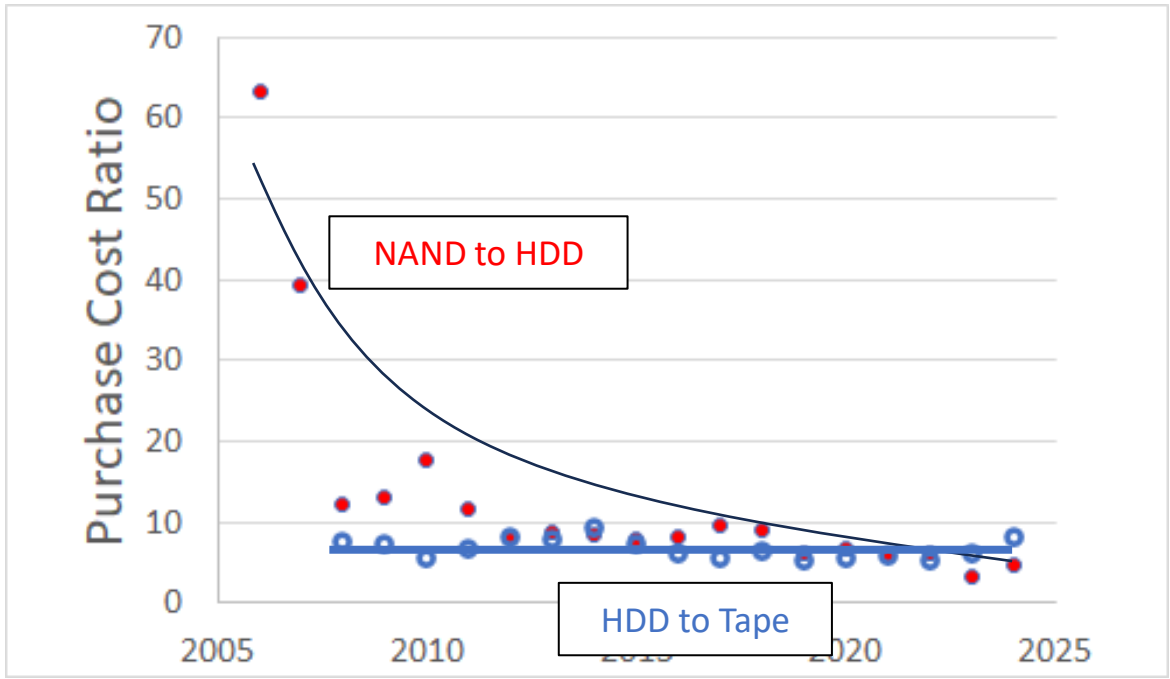
HDD >> SSD bit shipments

More **Tape** demand: Cheap, energy efficient and easier to use (S3)

Cost Trends of NAND, HDD and LTO tape

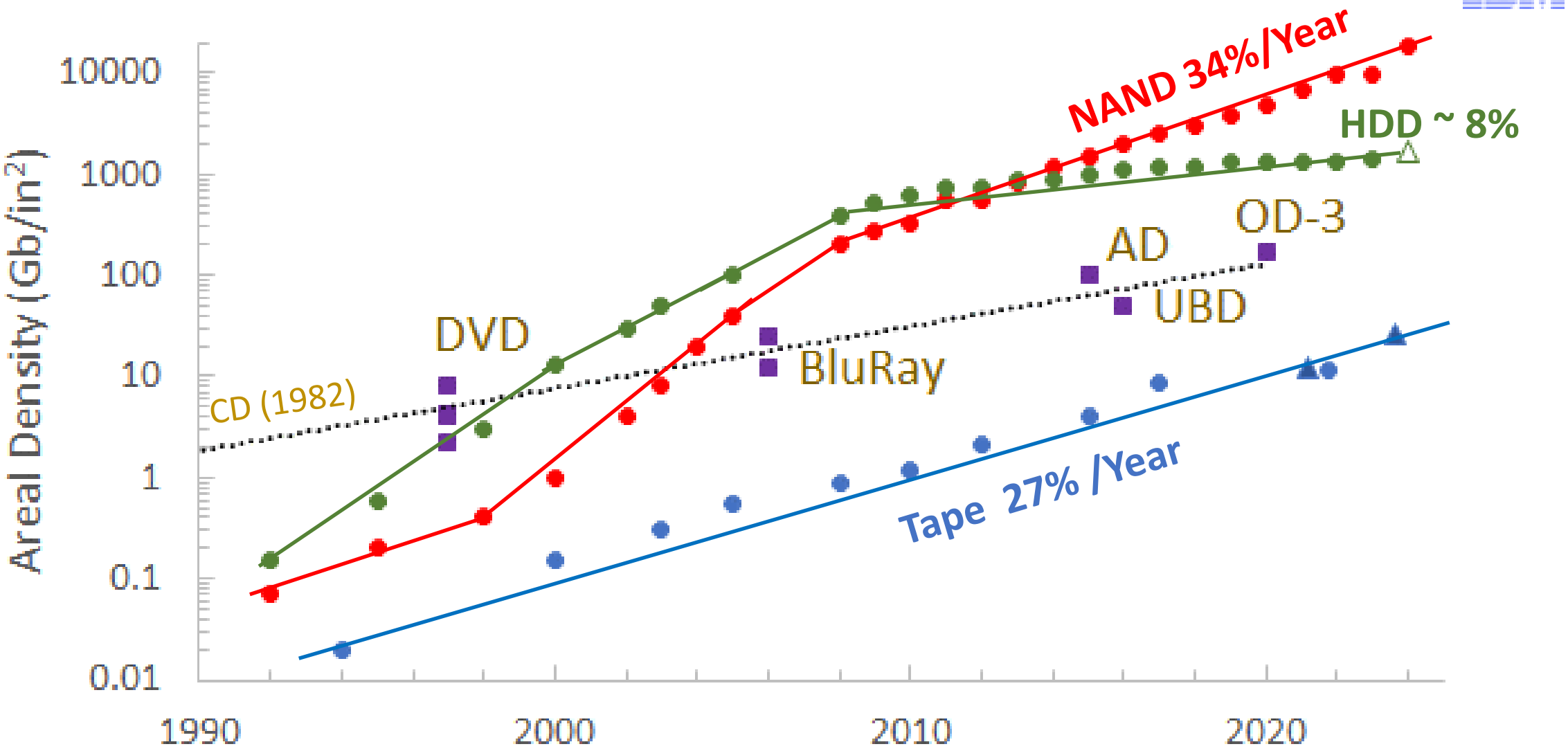
- Purchase cost decreases for all technologies
  - Tape to HDD cost ratio stable
  - NAND became relative to HDD more affordable





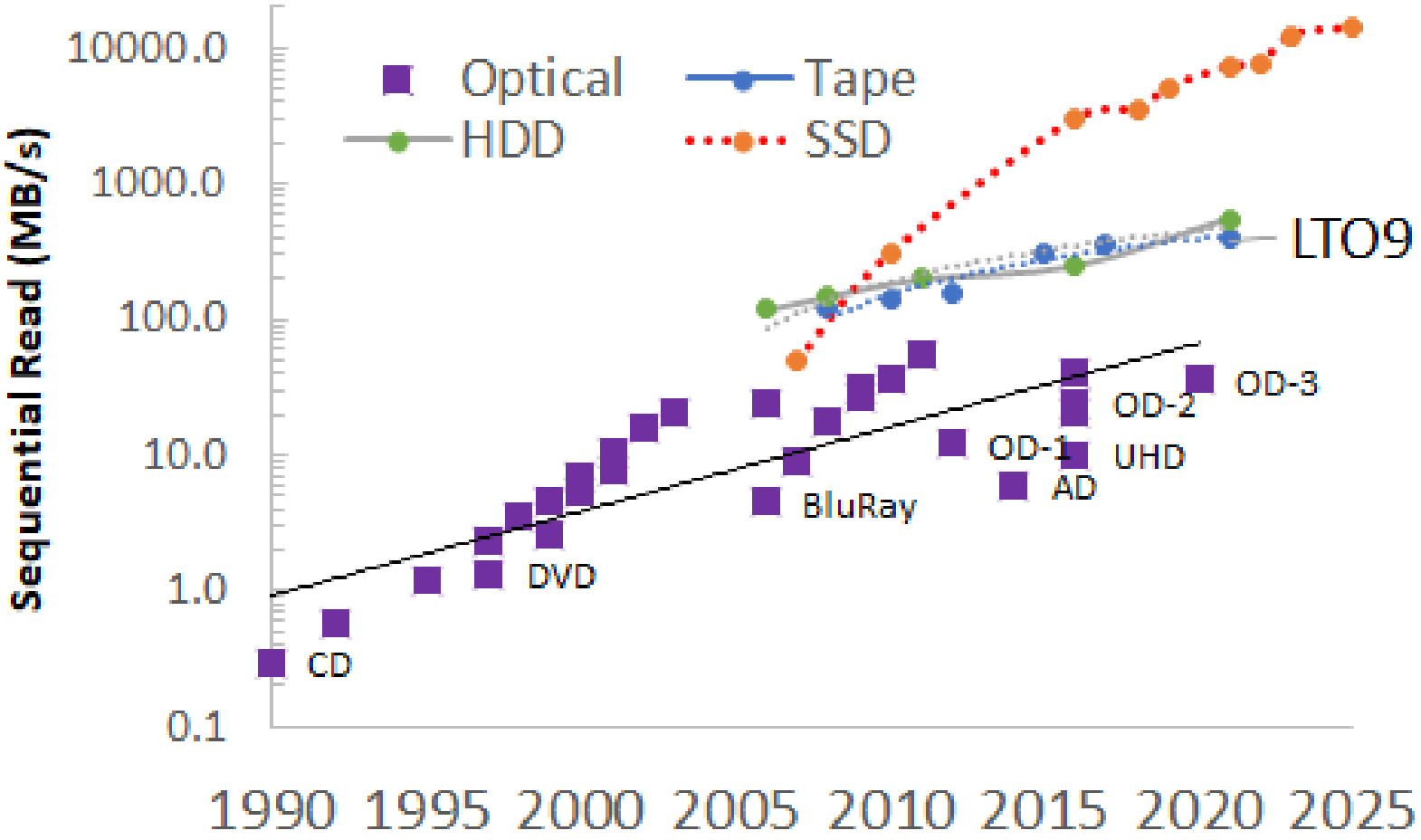
For Tape the Price per TB is for compressed storage cartridge cost

Areal Densities of NAND, HDD, Tape, Optical



Optical Storage: have seen limited adoption for archival storage. Optical Archival (OD-3) was discontinued in 2023.

Sequential Read Speeds of SSD, HDD, Tape, Optical

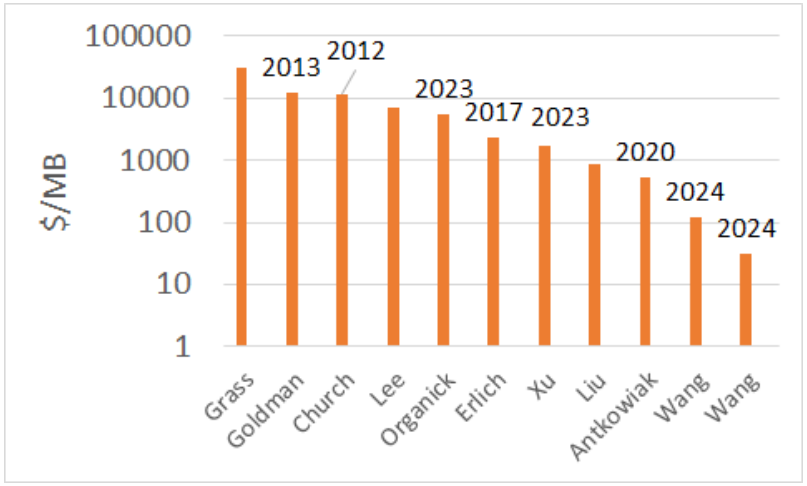


Tape faster sequential Read speed compared to single actuator **HDD**, **Optical** disk

Tape drives read and write with 32 heads in parallel to achieve this.

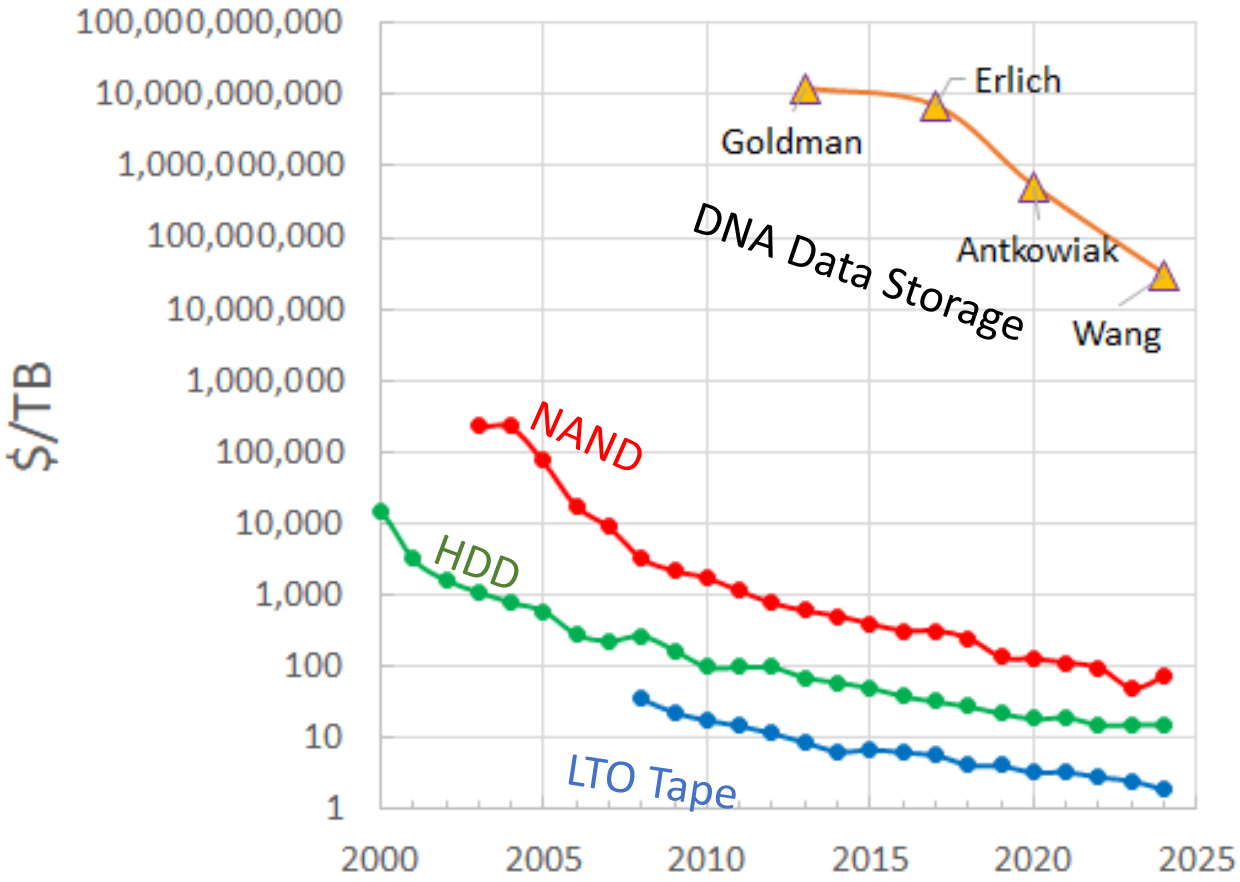
DNA Data Storage vs Traditional Data Storage Cost

DNA Data Storage cost by different authors



Adapted from Wang et al, 2024

doi.org/10.1002/advs.202411354

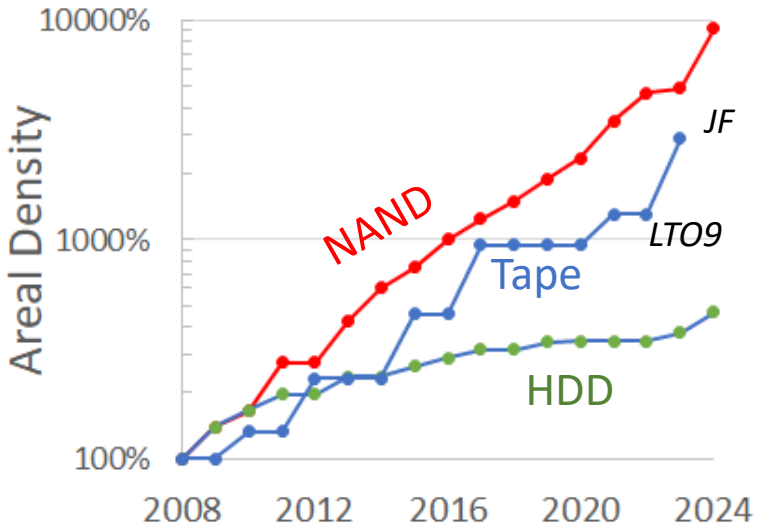


DNA Storage slow and expensive

Summary

- **Tape Storage:** continues to evolve, ensuring effectiveness for future needs.
- **HDD**: improvements slow down.
- **NAND**: well-suited for hot storage but not for archival purposes.
- **Lack of Alternatives**: Within the foreseeable future (within 10 years), there are no viable alternatives to Tape, HDD, and NAND storage.
- **AI** will lead to storage demands across the tiers

Yearly Change 2012-2024				2024		
	NAND	HDD	LTO MEDIA	NAND	HDD	LTO MEDIA (compressed)
Bit Shipments (EB)	33%	10%	12% (12-23)	867	1230	153 (‘23)
Cost/Bit ($/TB)	-18%	-14%	-14%	75	16	2
Areal Density (Gb/in2)	34%	8%	26% (12-23)	~18000	~ 1800	26 (JF) (compressed)



Appendix

DATA METHODOLOGY

- This talk builds on studies by
  G. Lauhoff et al, "Storage Infrastructure in the AI Era," IEEE Trans Mag 61, 4 (2025)
  R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018) *and our previous Library of Congress presentations*
- Data obtained from publicly available sources
- Parameters considered
  - Tape: LTO media only
  - HDD: All hard disk drives with no differentiation for capacity, disk diameter, platter number
  - NAND: All chip shipments (not just SSD)
- Data qualifiers
  - Cost/Bit is determined as **Total Revenue / Total Bits Shipped** and is not representative of any single product
  - Areal Density is determined as the “best” or “highest” value in a shipped product
- Tape data – LTO Media Only
  - Media cost/bit is based on web-based pricing at www.tape4backup.com
  - Data is for media only and does not include contributions from drive sales, library sales